Polymers (Part 1) – Introduction and Isomerism

Learning Outcomes

Students should be able to:

(a) interpret, and use the nomenclature, general formulae and structural formulae (including displayed formulae) of the following classes of compounds:
- (i) hydrocarbons (alkanes, alkenes and benzene)
- (ii) halogenoalkanes
- (iii) alcohols (including primary, secondary and tertiary)
- (iv) aldehydes and ketones
- (v) carboxylic acids
- (vi) esters
- (vii) amines
- (viii) amides

(b) interpret, and use the following terminology associated with organic reactions:
- (i) functional group
- (ii) addition, substitution, elimination
- (iii) condensation, hydrolysis
- (iv) oxidation and reduction
  [in equations for organic redox reactions, the symbols [O] and [H] are acceptable]

(c) describe constitutional (structural) isomerism

(d) describe *cis*-*trans* isomerism in alkenes, and explain its origin in terms of restricted rotation due to the presence of bonds [use of *E*, *Z* nomenclature is **not** required]

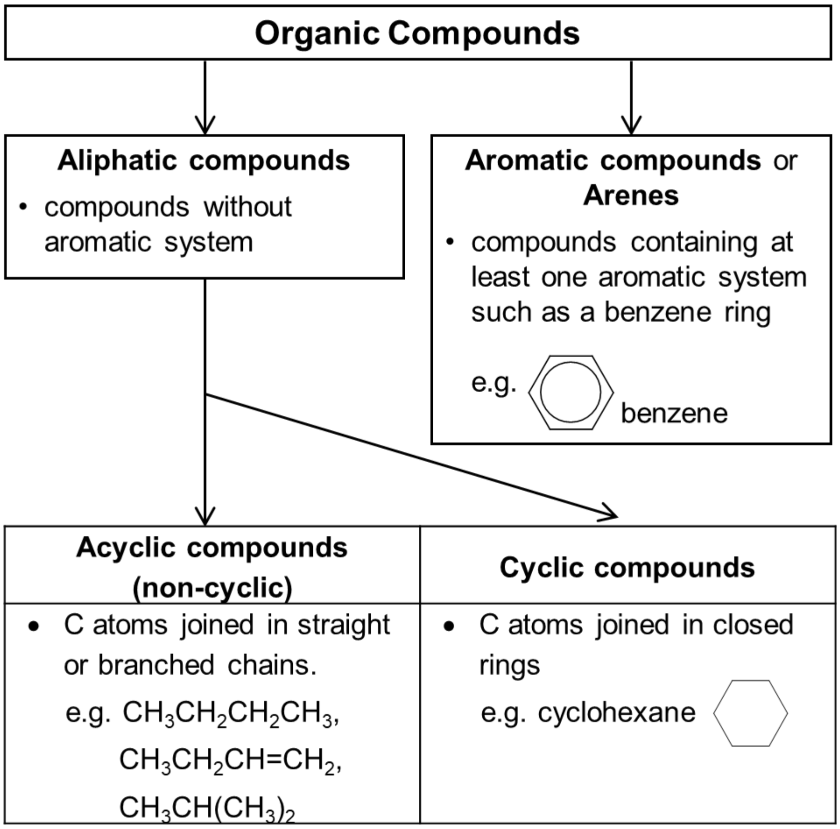
(e) deduce the possible isomers for an organic molecule of known molecular formula

(f)
- (i) describe the shapes of the ethane, ethene and benzene molecules
- (ii) explain the shapes of, and bond angles, in the ethane, ethene and benzene molecules in relation to σ and π carbon-carbon bonds
- (iii) predict the shapes of, and bond angles in, molecules analogous to those specified in (f)(ii)

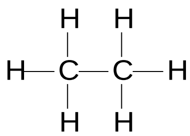
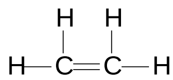
1 INTRODUCTION TO ORGANIC COMPOUNDS

Success Criteria:
- I can classify organic compounds into aliphatic, aromatic, acyclic and cyclic compounds.
- I can explain and recognise what saturated and unsaturated organic compounds are.

1.1 Classifications of Organic Compounds



Saturated and unsaturated organic compounds

An organic compound which contains only single bonds (C–C and C–H bonds in hydrocarbons) is said to be **saturated.** 	An organic compound which contains 1 or more double / triple bonds (C=C, C=O and C≡N bonds) is said to be **unsaturated**. 

1.2 Structural Formulae of Organic Compounds

Success Criteria:
- I can interpret and draw different types of structural formulae (eg condensed, displayed, skeletal and stereochemical).

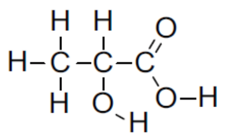
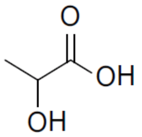
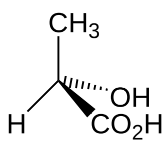
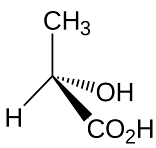
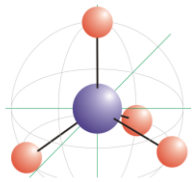
Video on Drawing Skeletal Formula.

https://tinyurl.com/skeletalformula

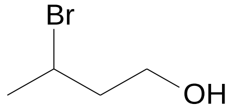
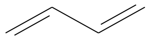
Lactic acid has a molecular formula of $C_3H_6O_3$ and an empirical formula of CH_2O.

A molecular formula does not show how the various atoms in the organic compound are actually connected to one another. Hence, structural formulae are used to represent organic compounds.

Below are the different structural formulae of lactic acid, $CH_3CH(OH)CO_2H$.

Type of Structural Formulae	Representation	Characteristics
Condensed	$CH_3CH(OH)CO_2H$	• shows the order of arrangement of atoms • bonds are not displayed
Displayed / Full structural		• shows **all** atoms and bonds in the molecule
Skeletal		• Carbon atoms in a straight chain are drawn in a zigzag manner • each end of a line represents a carbon if other symbol of an atom is **not** written • C–H bonds at each C are **not** shown. • each C forms 4 bonds. Any "missing" bond not drawn out in a skeletal structure would be a C–H bond.
Stereochemical (for optical isomers where a C has four different groups attached)	 or 	• shows 3-D spatial arrangement of bonds, atoms and / or groups of atoms in a molecule • a dashed line (''''''''''') represents a bond **<u>into</u>** the plane of the paper • a wedged line (▬) represents a bond **<u>out</u>** of the plane of the paper 

More examples of skeletal structures.

Condensed formula	$CH_3CH(Br)CH_2CH_2OH$	$CH_2{=}CHCH{=}CH_2$
Skeletal formula		

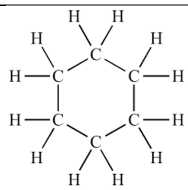
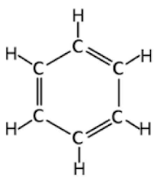
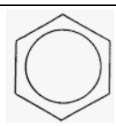
Checkpoint 1 

Complete the following table.

Type of formula	Compound	Compound
Condensed	$HOCH_2CH_2OH$	$CH_3CH{=}CH_2$
Displayed / full structural		
Skeletal		

1.3 Representation of carbon rings in formulae

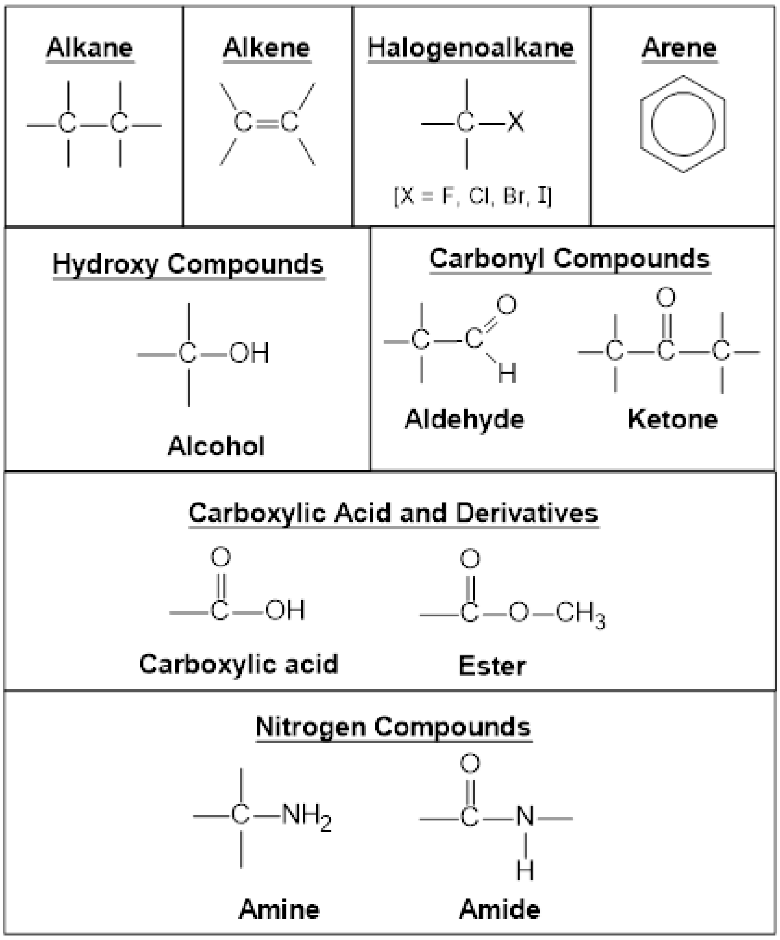
Cyclic rings of atoms are often represented by their skeletal formula.

Name	Cyclohexane	Benzene
Molecular Formula	C_6H_{12}	C_6H_6
Structural Formula		
Skeletal Formula		

1.4 Functional groups

Success Criteria:
- I can identify, name and draw the functional groups

A **functional group** is made up of an atom (e.g. C*l*) or a group of atoms (e.g. –OH, –CN) responsible for the characteristic chemical properties of an organic compound.

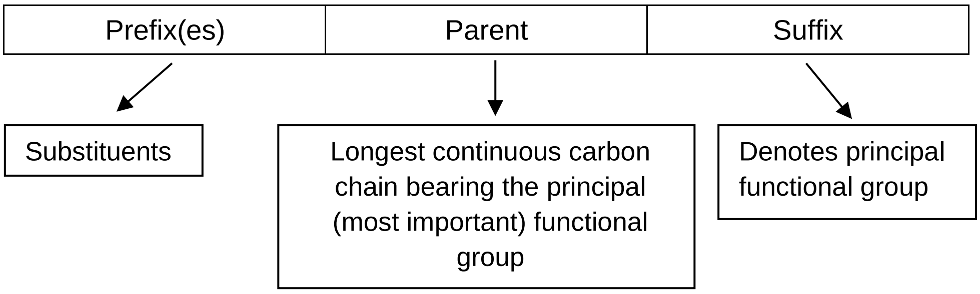


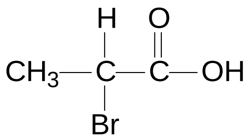
1.5 Nomenclature of Organic Compounds

Success Criteria:
- I can name the organic compound using IUPAC system and construct the structural formula of a compound from its IUPAC name.

Naming of organic compounds is based on a systematic method developed by the **I**nternational **U**nion of **P**ure and **A**pplied **C**hemists (IUPAC).

Every IUPAC name consists of a **parent** (or **stem**), a **suffix** and as many **prefixes** as necessary.





<u>2-bromo</u>propan<u>oic acid</u>

(a) Parent

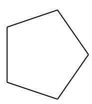
In the <u>aliphatic</u> unbranched chain system, the name of the parent takes its name according to the number of carbon atoms in the longest continuous chain.

no. of carbon	*parent*
1	**meth-**
2	**eth-**
3	**prop-**
4	**but-**
5	**pent-**

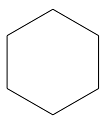
no. of carbon	*parent*
6	**hex-**
7	**hept-**
8	**oct-**
9	**non-**
10	**dec-**

For **saturated** hydrocarbon, the name of the parent ends with **-an-**. For an <u>unsaturated</u> hydrocarbon with C=C bond, the name of the parent ends with <u>-en-</u>.

In **alicyclic** system, the word **cyclo** is added to the front of the root corresponding to the same number of C atoms.



cyclopentane



cyclohexane

(b) Suffix

- It indicates the **principal functional group** of the organic compound.
- *Table 1* gives the list of the functional groups in decreasing order of priority as suffix. The functional group(s) other than principal functional groups are as prefix(es).

decreasing priority

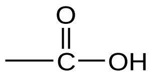
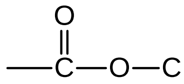
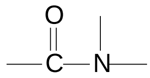
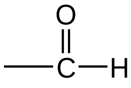
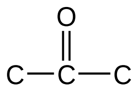
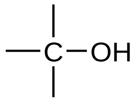
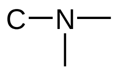
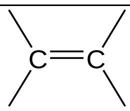
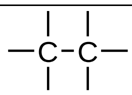
Functional group	*Type of compound*	*Suffix*
	**carboxylic acid**	**-oic acid**
	**ester**	**(alk)yl …-oate**
	**amide**	**-amide**
 (–CHO)	**aldehyde**	**-al**
	**ketone**	**-one**
	**alcohol**	**-ol**
	**amine**	**-amine**
	**alkene**	**-ene**
	**alkane**	**-ane**

Table 1. Suffixes of various functional groups

(c) Prefix

- Once the principal functional group is identified, any other functional group in the compound is treated as a substituent on the parent chain, and is named by a prefix.
- A **substituent group** is an atom or group of atoms substituted in place of a hydrogen atom on the parent chain of a hydrocarbon.

Substituent group	*Prefix*
–F	fluoro-
–C*l*	chloro-
–Br	bromo-
–I	iodo-
–OH	hydroxy-
$–NH_2$	amino-

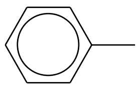
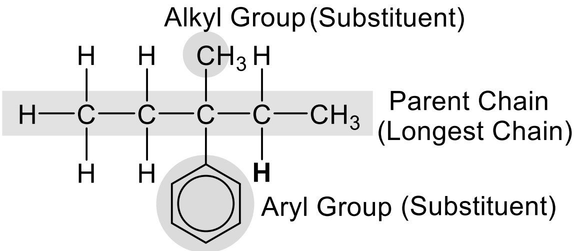
Substituent group	*Prefix*
Alkyl group CH_3– CH_3CH_2– $CH_3CH_2CH_2$–	 methyl- ethyl- propyl-
Aryl group  or C_6H_5–	phenyl-

Table 2. Common prefixes

Arabic numerals (1,2,3) are used to indicate the **positions of attachment** of substituents, C=C bonds and certain principal functional groups. They are known as **positional numbers**.

3-methyl-3-phenylpentane

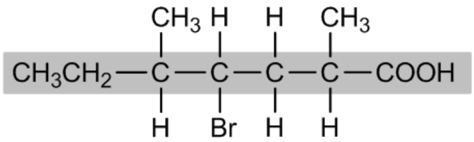
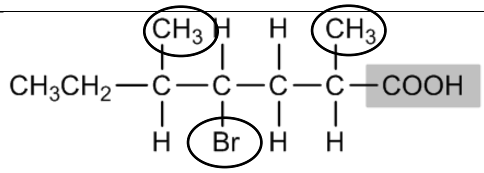
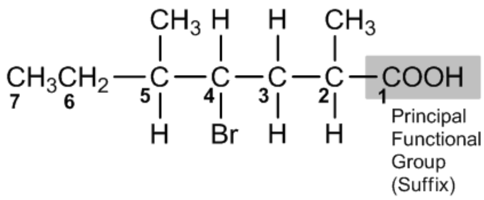
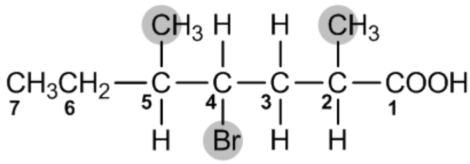


For carbon chain with 3 carbon or more, we need to specify the position of the principal functional group. The position of the double bond is denoted using the smaller carbon number.

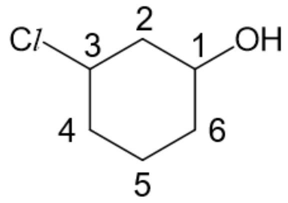
E.g. But-2-ene shows that the C=C is from C2 to C3

$CH_3CH_2CH=CH_2$ But-1-ene	$CH_3CH=CHCH_3$ But-2-ene

Key Steps in naming organic compounds

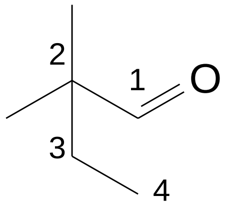
	Steps	*Example*
1	Identify the longest continuous carbon chain containing the principal functional group (functional group with the highest priority). Count the number of C atoms. This gives the **parent**.	 ● no. of C atoms in parent chain = 7 **parent**: **hept-**
2	Identify all the functional groups and write the <u>principal functional group</u> as the <u>suffix</u> and the rest as the prefixes.	 ● carboxylic acid functional group is of the highest priority **suffix**: **-<u>an</u>oic acid** **Prefixes:** “bromo-“ and “methyl-“
3	Number C atoms in the longest chain (from one end) such that: i) the **principal functional** group will be assigned the lowest possible number. ii) and then the **lowest** individual numbers for the substituents.	
4	String together the <u>prefix(es)</u>, <u>parent</u>, and <u>suffix</u> taking note of the following rules. ● If the same substituent appears more than once, use *di-(two), tri-(three), tetra-*(four), etc. The appropriate positional number is still required even if the groups are connected to the same carbon on the parent chain. ● Different prefixes are listed in alphabetical order; multiple prefixes like *di-* and *tri-* do not affect the alphabetical order. Commas (,) are used to separate <u>numbers</u> and hyphens (-) to separate <u>numbers</u> and alphabets.	 **Prefixes:** “bromo-“ and 2 × “methyl-“ **Position of** “bromo-“: carbon 4 **Positions of** “methyl-“: on carbon 2 and 5 **Parent**: heptanoic acid The name of the compound is **<u>4-bromo-2,5-dimethylheptanoic acid</u>.**

Worked Example 1



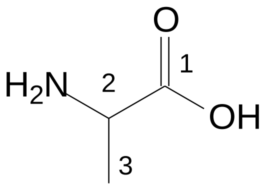
parent: cyclohex
suffix: -ol
prefix: chloro on carbon 3

The name is 3-chlorocyclohexanol



parent: but
suffix: -al
prefix: 2 × methyl on carbon 2 and 2

The name is 2,2-dimethylbutanal



parent: prop
suffix: -oic acid
prefix: amino on carbon 2

The name is 2-aminopropanoic acid

1.6 Homologous Series

A **homologous series** is a family of organic compounds having the same **functional group**; **each successive member increases by a –CH_2– unit**.

Compounds in the same homologous series:

- can be represented by a general molecular formula (e.g. alkane, C_nH_{2n+2}).
- show a gradual change in physical properties (density, melting and boiling points, solubility, etc.) with an increase in molar mass.
- have similar chemical properties as they have the same functional group(s).
- can usually be prepared by similar methods.

Homologous series of alkanes

Formula	*Name*	*Boiling point / ºC*
CH_4	methane	–162
CH_3CH_3	ethane	–89
$CH_3CH_2CH_3$	propane	–42

Homologous series of alkene

Formula	*Name*
$CH_2{=}CH_2$	Ethene
$CH_3CH{=}CH_2$	Propene
$CH_3CH_2CH{=}CH_2$	But-1-ene
$CH_3CH{=}CHCH_3$	But-2-ene

Homologous series of alcohol

Formula	*Name*
CH_3OH	Methanol
CH_3CH_2OH	Ethanol
$CH_3CH_2CH_2OH$	Propan-1-ol
$CH_3CH(OH)CH_3$	Propan-2-ol

Note:
For carbon chain with 3 carbon or more, we need to specify the position of the principal functional group.

Checkpoint 2

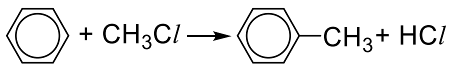
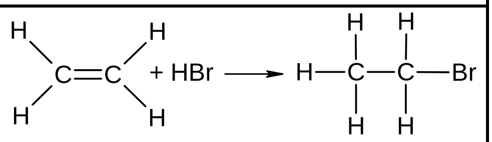
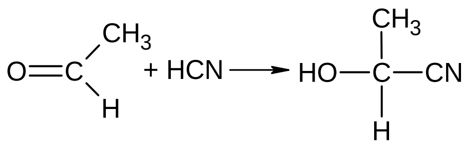
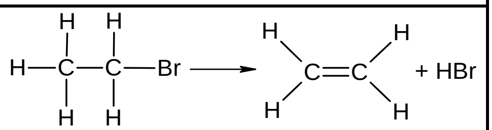
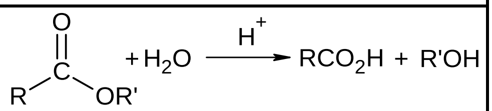
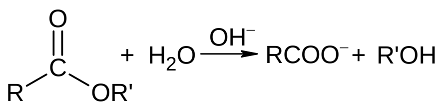
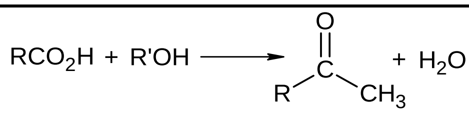
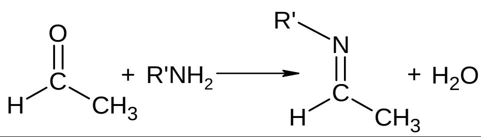
1. Draw the structure of the following compounds.

IUPAC name	compound
pentan-3-one	
2-hydroxy-4-methylhexanal	
3-bromo-1-methylcyclopentene	

2 TYPES OF REACTIONS FOR ORGANIC COMPOUNDS

Success Criteria:

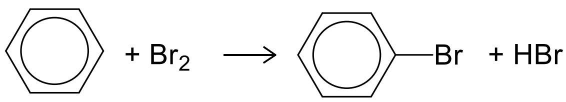
- I can identify the type of organic reaction by looking at the changes in the organic molecule in a given equation.

Type of reaction	*Characteristics*	*Examples*
Substitution	• An atom or a group of atoms is **<u>substituted</u>** (replaced) by another atom or group of atoms	$CH_4 + Cl_2 \rightarrow CH_3Cl + HCl$ One H of methane is substituted by a C*l* atom.  One H of benzene is substituted by a methyl group.
Addition	• Occurs only when there is unsaturation in reactant molecule (double or triple bonds) • Two species react to form a single product without any elimination of atom	 
Elimination	• The reverse of addition reactions • Atoms or a group of atoms are removed to form a product molecule with a **double bond**	
Hydrolysis	• "Hydro" means <u>water</u> and "-lysis" means <u>breaking</u>. • A reaction in which a molecule is spilt into 2 or more smaller species by the action of water • An acid or alkali is often used as catalyst	 
Condensation	• The reverse of hydrolysis • **Two molecules** react to form a **bigger molecule** with the elimination of a small molecule, e.g. H_2O	 

Type of reaction	*Characteristics*	*Examples*
Oxidation	• 1 or more **O** is **added** to the molecule *and/or* • 1 or more **H** is **removed** from the molecule	CH_3CH_2OH + 2**[O]** → CH_3CO_2H + H_2O $CH_2{=}CH_2$ + 6**[O]** → $2CO_2$ + $2H_2O$ In balancing an organic redox equation, the symbol **[O]** is used to denote each O contributed by the oxidising agent such as $KMnO_4$ or $K_2Cr_2O_7$. "O_2" is used if the oxidising agent is O_2.
Reduction	• 1 or more **O** is **removed** from the molecule *and/or* • 1 or more **H** is **added** to the molecule.	CH_3CO_2H + 4**[H]** → CH_3CH_2OH + H_2O In balancing an organic redox equation, the symbol **[H]** is used to denote each H contributed by the reducing agent such as $LiAlH_4$ or $NaBH_4$. "H_2" is used if the reducing agent is H_2.

Checkpoint 3 

Classify each of the following organic reactions as a substitution, addition, elimination, hydrolysis, condensation, oxidation or reduction reaction.

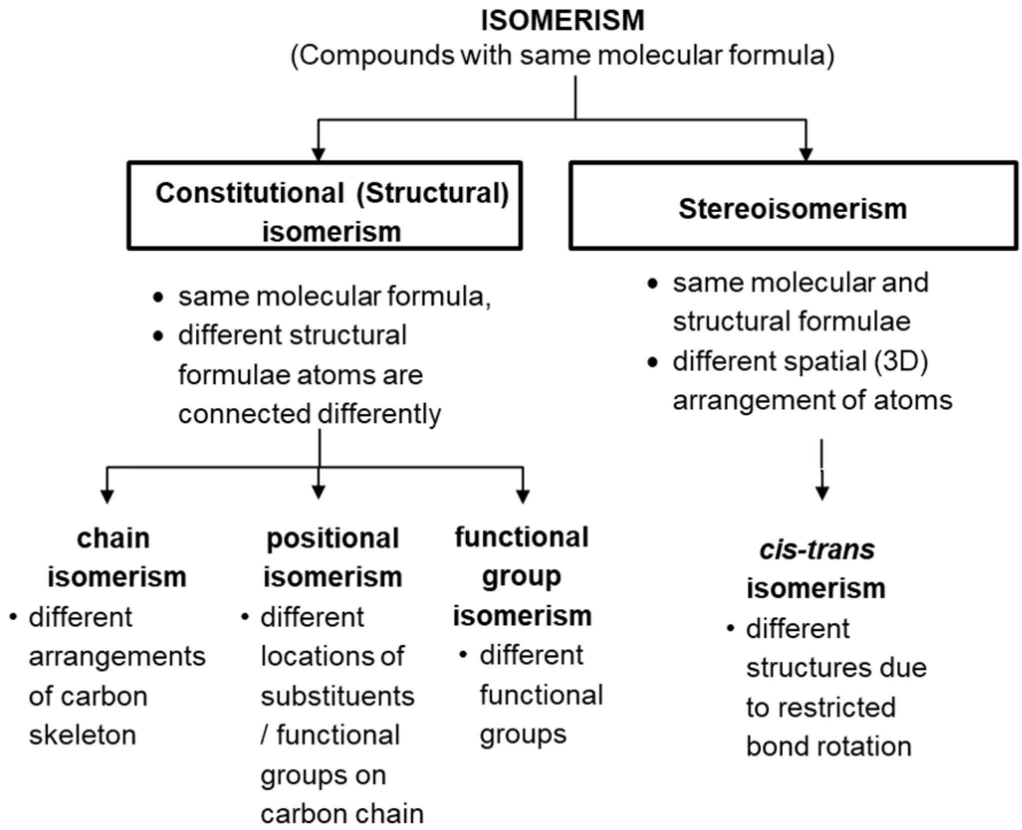
1	$CH_3COOH + CH_3CH_2OH \longrightarrow CH_3COOCH_2CH_3 + H_2O$	
2		
3	$CH_3CHBrCH_2CH_3 \xrightarrow{OH^-} CH_3CH{=}CHCH_3 + HBr$	
4	$CH_2{=}CHCH_3 + 5[O] \longrightarrow CH_3CO_2H + CO_2 + H_2O$	

3 ISOMERISM

Note:
bonds have to be broken in order for isomer A to be converted to isomer B.

Isomerism refers to the **existence of two or more stable compounds** with the **same molecular formula** but **different arrangement** of the **atoms**. These compounds are known as **isomers.**

There are 2 **major** types of isomerism: **constitutional (structural) isomerism** and **stereoisomerism.**

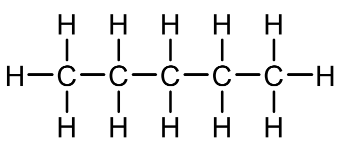


3.1 STRUCTURAL ISOMERISM (CONSTITUTIONAL ISOMERISM)

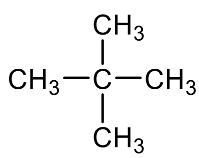
Success Criteria:
- I can describe and draw constitutional (structural) isomers

Structural isomers have the **<u>same molecular formula</u>** but **<u>different structural formulae</u>**; i.e., at least one atom is bonded to a different atom in one isomer compared to another.

(i) Chain Isomers
e.g. structural isomers of C_5H_{12}



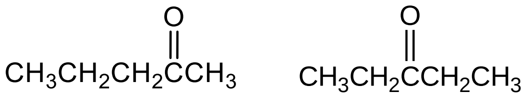
pentane



2,2-dimethylpropane

Both share the same molecular formulae but differ in the longest continuous hydrocarbon chain.

(ii) Positional Isomers
e.g. pentan-3-one vs pentan-2-one



pentan-2-one pentan-3-one

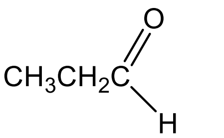
Both share the same functional group but different location of C=O group on the longest continuous hydrocarbon chain.

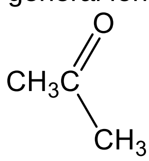
Chain and position isomers have **different physical properties** such as density, solubility, melting and boiling points as the **surface area of contact between molecules** are different. These isomers have **similar chemical properties** as they have the same functional groups.

(iii) Functional group isomers
e.g. CH_3OCH_3, dimethyl ether and CH_3CH_2OH, ethanol

There are **3 common pairs of functional group** isomers.

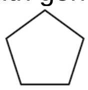
- aldehydes and ketones with general formula | $C_nH_{2n}O$



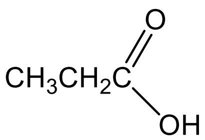


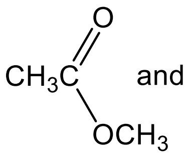
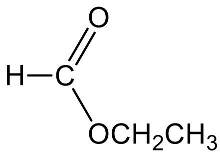
- alkenes and cycloalkanes with general formula | C_nH_{2n}

$CH_3CH_2CH_2CH{=}CH_2$



- carboxylic acids and esters with general formula | $C_nH_{2n}O_2$



 and 

Functional group isomers have **different** physical and chemical properties.

<u>Checkpoint 4</u> 

Draw all the structural isomers of molecular formula C_6H_{14}.

3.2 STEREOISOMERISMS

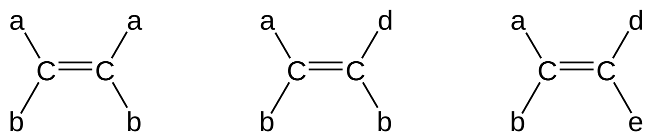
Stereoisomers have the same molecular and structural formulae. The corresponding atoms are bonded to the same atoms but differ in the spatial (3D) arrangements of their bonds.

3.2.1 Cis-trans Isomerism

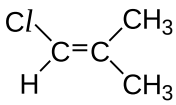
Success Criteria:
- I can state the two structural features required for an alkene to undergo cis-trans isomerism.
- I can name and draw cis- and trans- isomers.

Two conditions are required for cis-trans isomerism to exist:
- restricted rotation about a bond, e.g. a double bond (usually C=C bonds)
- two different groups on **<u>each</u>** of the carbon atoms with restricted rotation.

e.g.

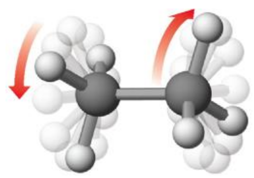
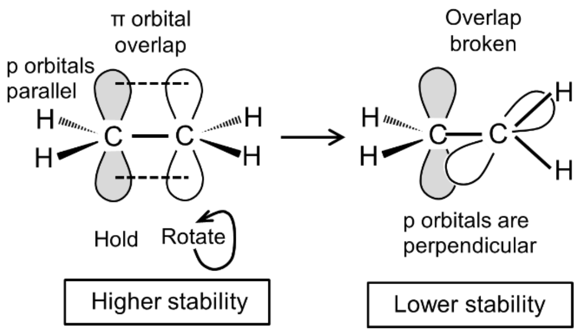
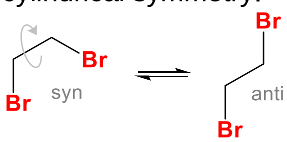
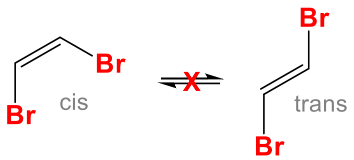


The compound below does not exhibit cis-trans isomerism as it has two methyl groups attached to one of the C atoms with restricted rotation.



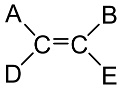
Note:
Free rotation about the single C–C bond may cause spatial arrangement of atoms across 2 C to differ but they are not isomers of each other as bond breaking process is not involved to convert 1 arrangement to the other.

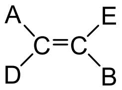
(i) Restricted rotation about single bonds versus double bonds

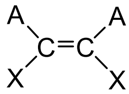
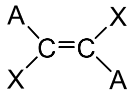
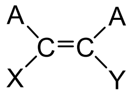
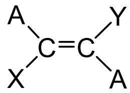
Single bond	Double bond
	
Free rotation is possible about σ bonds due to their cylindrical symmetry.  Rotation does not cause any bond to be broken.	Free rotation is not possible about a double bond.  Conversion of cis-isomer to trans-isomer requires the π bond to be broken

(ii) Naming of cis-trans Isomers

Note:
Alkenes with four different substituents across C=C also exhibit cis-trans isomerism. Another naming convention (E / Z) is used instead.
**E/Z naming is not in H1 syllabus.

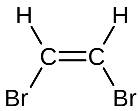
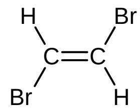
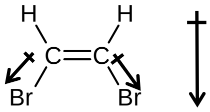
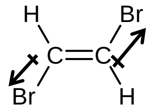




***cis*-isomers**	***trans*-isomers**
have identical atoms / groups of atoms on the **<u>same</u>** side of the double bond	have identical atoms / groups of atoms on diagonally **<u>opposite</u>** sides of the double bond
e.g. 	
e.g. 	

(iii) Properties of cis-trans isomers

Cis-trans isomers have the same chemical but different physical properties.

	cis-isomer	trans-isomer
Structural Formula		
Net Polarity	 polar molecule	 non-polar molecule
Boiling Point	has a higher boiling point as more energy is needed to overcome stronger permanent dipole-permanent dipole interactions between the molecules	has a lower boiling point as less energy is needed to overcome weaker intermolecular instantaneous dipole-induced dipole interactions
Melting Point	has lower melting point due to poorer packing efficiency, leading to less intermolecular forces per unit volume	has a higher melting point due to better packing efficiency of molecules (packs better in a crystalline lattice due to its more symmetrical shape), leading to more intermolecular forces per unit volume

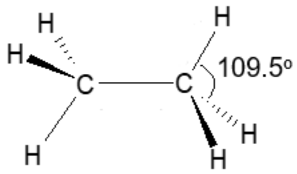
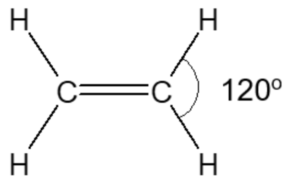
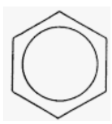
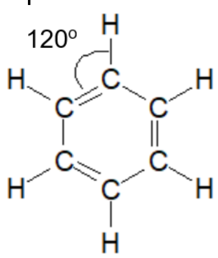
(iv) Molecules containing two or more cis-trans C=C

In general, a molecule with "n" cis-trans C=C has a maximum of 2^n stereoisomers.

For a compound with three cis-trans C=C, eight (2^3) stereoisomers are expected.

4 SHAPES OF ETHANE, ETHENE AND BENZENE

Success Criteria:
- I can describe the shapes of the ethane, ethene and benzene molecules
- I can explain the shapes of, and bond angles, in the ethane, ethene and benzene molecules in relation to σ and π carbon-carbon bonds

Molecule	Shape	Bonding
Ethane C_2H_6	Tetrahedral with respect to each C atom 	C–H σ bond (head-on overlap of orbitals) C–C σ bond (head-on overlap of orbitals)
Ethene C_2H_4	Trigonal planar with respect to each C atom 	C–H σ bond (head-on overlap of orbitals) C=C (1 σ + 1 π) - σ bond (head-on overlap of orbitals) - π bond (side way overlap of p orbitals)
Benzene C_6H_6 	Trigonal planar with respect to each C atom 	C–H σ bond (head-on overlap of orbitals) C=C (1 σ + 1 π) - σ bond (head-on overlap of orbitals) - π bond (side way overlap of p orbitals) C–C σ bond (head-on overlap of orbitals)

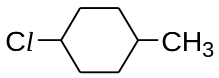
POLYMERS (Part 1) TUTORIAL

Structure and naming

1 Give the IUPAC name for each compound.

(a) $CH_3CH(CH_3)CH_2CH(OH)CH_3$

(b) CH_2=CHCH=CHBr

(c) 

(d) $CH_3CH(CO_2H)CH_2CH_3$

2 Draw the skeletal formula of each compound.

(a) 2,2,4-trimethylhexane

(b) nona-1,3,5-triene

(c) 2,4-dibromomethylbenzene

(d) 4-hydroxylheptan-3-one

(e) 1-ethyl-3,3-dimethylcyclopentane

(f) 2-amino-3-ethyl-2-methylpentane

3 For each part, the name given is **incorrect**. Draw the skeletal formula for each and give its correct IUPAC name.

(a) 2-ethylpentane

(b) 2-chloro-2-ethylbut-3-ene

(c) 2,3-diethylcyclopentane

(d) 1,1-dimethy-3-propylhexane

Type of reaction

4 Classify each reaction as ***addition***, ***elimination***, ***condensation, oxidation***, ***reduction*** or ***substitution***.

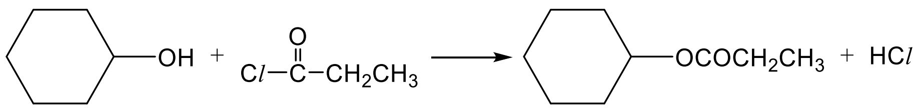
(a) $CH_3CH_3 + Br_2 \longrightarrow CH_2BrCH_3 + HBr$

(b) $CH_2{=}CHCH_3 + Br_2 \longrightarrow BrCH_2CH_2BrCH_3$

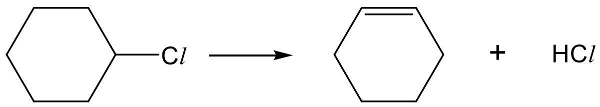
(c) $CH_3CH_2CH_2OH + 2[O] \longrightarrow CH_3CH_2CO_2H + H_2O$

(d) $CH_3CO_2H + 2[H] \longrightarrow CH_3CHO + H_2O$

(e)



(f)



Balancing equation for organic redox reaction

5 Balance each equation with either [O] or [H]. Add H_2O whenever necessary.

(a) $CH_3CH_2OH \longrightarrow CH_3CHO$

(b) $CH_3CH_2CONH_2 \longrightarrow CH_3CH_2CH_2NH_2$

(c) $CH_3CH{=}CHCH_3 \longrightarrow 2CH_3CO_2H$

(d) $CH_3CO_2CH_3 \longrightarrow CH_3CH_2OH + CH_3OH$

Constitutional Isomerism (Structural Isomerism)

6 A halogenoalkane has the molecular formula $C_3H_5Cl_3$.

Which are the possible names of the isomers of this compound?

1 1,1,1-trichloropropane
2 1,2,2-trichloropropane
3 2,2,3-trichloropropane

A **1, 2** and **3** are correct **B** **1** and **2** only are correct

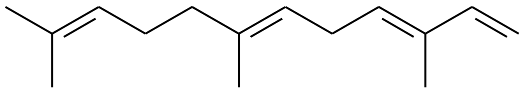
C **2** and **3** only are correct **D** **1** only is correct

Cis-trans Isomerism

7 How many structural and *cis-trans* isomers are there in dichloropropene, $C_3H_4Cl_2$?

A 3 **B** 5 **C** 6 **D** 7

8 *α–Farnesene* is a constituent of the natural wax found on apples. It is also responsible for the characteristic odour of green apples.



α–Farnesene

How many *cis-trans* isomers does this molecule have?

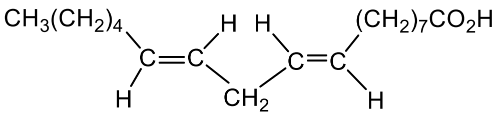
A 2 **B** 4 **C** 8 **D** 16

9 Low fat sunflower spreads which are high in polyunsaturated contain esters of linoleic acid.

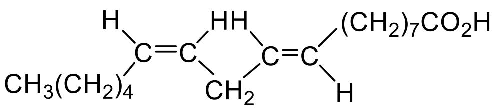
$$CH_3(CH_2)_4CH{=}CHCH_2CH{=}CH(CH_2)_7CO_2H$$

On the lid of a brand of spread, it is claimed that the spread contains virtually no *trans* fatty acid. Which isomer does **not** contain a *trans* linkage that could be present in the spread?

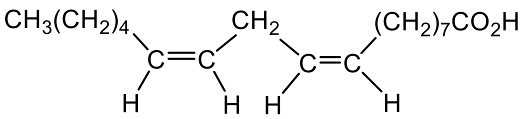
A



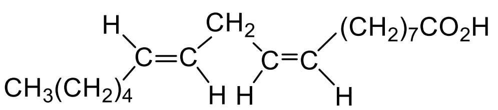
B



C



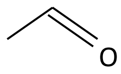
D



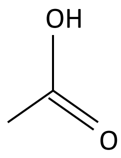
10 Draw all the structural isomers of the hydrocarbon C_4H_8 and give their IUPAC names. One of these structural isomers also exists as a pair of *cis-trans* isomers. Identify this isomer and draw the *cis-* and *trans-* isomers.

Application Question

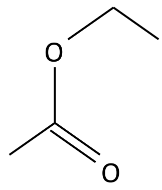
11 Poor processing or storage of wine can lead to the build-up of certain compounds that can spoil the flavour and aroma of the wine. The structures of three such compounds are shown below.



A



B



C

(a) Give the molecular formula for **A**, **B** and **C** respectively.

(b) State the functional group(s) present in **A**, **B** and **C** respectively.

(c) Use the table of characteristic values for infra-red absorption in the *Data Booklet* to answer this part.

With reference to the structures of **A**, **B** and **C**, identify an infra-red absorption range that will be shown by:

(i) **B** only.

(ii) **C** but not **A**.

(iii) all three compounds (other than absorptions due to C–H bond).